ABSTRACT
              Noting that current cognitive theories focus on the
belief that knowledge is an organized collection of long-term
structures upon which various processing mechanisms operate, this
paper argues that mental functioning may be more readily
characterized if the idea of abstract long-term associations and
structures is abandoned. It proposes a model of cognition in which
mental relations are transient functional relations, and in which
psychological permanence is a functional characteristic of the
neuronal system. It explains cognition and other aspects of mental
life in terms of the activity of anatomically distributed
constellations of neuronal elements, which are conceived of as
physiological microsystems that are capable of generating specialized
awareness experiences. The paper terms the overall mental counterpart
of the combined activity of these elements "schema-of-the-moment"
(SOM), a constantly changing phenomenon involving both global and
focal experiences. It then discusses the three distinguishable, but
not separate, components of SOM: the background, dominant, and
independently functioning components. (Author/FL)

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MORE ON THE FUNCTIONAL VIEW OF COGNITION:
A BIOFUNCTIONAL MODEL OF MENTAL CONTENT;
MENTAL STRUCTURES, AWARENESS, AND ATTENTION

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Abstract

Central to current cognitive theories is the belief that knowledge
is an organized collection of long-term structures upon which
various information processing mechanisms operate. Consequently
much research has been devoted to investigating the organizational
and processing aspects of knowledge representations. This paper
proposes a shift in the locus of theoretical analysis. Following
Bartlett, we argue that mental functioning may be more readily
characterized if the idea of abstract long-term associations and
structures is abandoned. An account of cognition is proposed in
which mental relations are transient functional relations, and in
which psychological permanence is a functional characteristic of the
neuronal system. Cognition and other aspects of mental life are
explained in terms of the activity of anatomically distributed
constellations of neuronal elements. These elements are conceived
of as physiological microsystems which are capable of generating
specialized awareness experiences. The overall mental counterpart
of the combined activity of these elements we call the schema-of-
the-moment. We hope that the model we are proposing can contribute
to bridging the gap between cognitive psychology and the
neurosciences.

More on the Functional View

of Cognition: A Biofunctional Model of

Mental Content, Mental Structures, Awareness, and Attention

This paper is the result of a substantial revision

of Iran-Nejad and Ortony (1982). The revision was

originally motivated by the desire to clarify some

of the areas in which the earlier paper was vague.

The result, however, turned out to be so different

from the original that this separate report seemed

warranted.

When psychological theories employ theoretical terms like

memory, representation, and structure, they often do so because the

descriptions and explanations of psychologically interesting

phenomena that result are at a sufficiently abstract level to be

informative and intelligible. As a first step in theory

construction the use of theoretical terms at a level of description

close to the phenomenological level is helpful, and probably

indispensable. However, the theories that result are often rather

vague and ill-constrained, and tend to lack predictive power (see,

for example, reviews of schema theory by Alba & Hasher, 1983 and

Thorndyke & Yekovitch, 1980). If this is true, then a sensible next

step would be to try to account for the phenomena of interest in

terms of more concrete constructs. In this paper we offer some

proposals for taking this step. To do this, we maintain that it is

necessary to reconsider the traditional notion of knowledge

representations as long-term (essentially) static structures. We

shall argue that the nature of mental content, schemata, awareness,

and attention may be more readily specifiable in terms of concrete

neurophysiologically-realistic constructs if one abandons the notion

of long-term static knowledge representations in favor of transient

dynamic patterns.

An interesting aspect of attempting to employ more concrete

theoretical constructs in psychological explanations is that it

sharpens the distinction between artificial intelligence and

cognitive psychology. The two cease to be simply methodological

variants of one another. Artificial intelligence is concerned with

characterizing cognition and intelligence in abstracto; its goal is

a "system-independent" specification of the cognitive software.

Theories in cognitive psychology must be more constrained. They

need to take into account not only the constraints imposed by

people's behavior, but also the sort of constraints likely to be

imposed by the biological hardware, since it is presumably these

that give cognition its uniquely human quality. Thus, while it

might seem reasonable to start by assuming that cognition can be

explained solely in terms of the formal characteristics of

psychological software, it may well be that this assumption cannot

be upheld. Certainly, arguments have been presented to this effect.

For instance, Eliashberg (1981) examined the properties of

hypothetical machines and argued that "the popular thesis that the

problem of the algorithms performed by the brain . . . has but

little to do with the problem of brain hardware" is inadequate.

Similarly, Kugler, Kelso, and Turvey (1980) claimed that "abstract
automata formally equivalent to the turing machine do not satisfy
the natural constraints that must be met by any actual, evolved
epistemic agent. . . . The cost variables imposed on organisms by
the laws of physics and biology are quite different from those
formally placed on the workings of abstract automata" (p. 5). We
share these views, believing that more attention needs to be devoted
to the functional characteristics of the physical systems that
exhibit the phenomena of interest. In fact, we believe that the
ultimate goal of cognitive psychology ought to be the specification
of the way in which the functional properties of the nervous system
make cognition possible.

There are other reasons for attempting to base an account of
cognition on relatively concrete constructs. One is that
neuroscientific models in general tend to be parsimonious. A
striking example is provided by the recent advances (e.g. Berlin &
Kay, 1969; Kay & McDaniel, 1978) in understanding the relationship
between the perception of color and the meaning of color terms in
different languages. It now seems that "all the basic color
categories of the languages of the world are based on . . . six
fundamental neural response categories, whose structures are
determined by the firing patterns of . . . cells in the visual
pathway" (Kay, 1981, p. 64). Only after taking account of the
physiology of color perception did it become possible to give a

unified explanation of the principles governing the way in which

people in different cultures speaking different languages talk about

the world of color.

For us, the most compelling reason for using relatively

concrete constructs in psychological theories is that their use

avoids some of the problems related to the metaphorical nature of

the theoretical terms traditionally employed. Terms like memory and

knowledge-representation are complex abstractions, and it is not at

all clear to what they refer. Many psychologists (e.g. Bartlett,

1932; Bransford, McCarrell, Franks & Nitsch, 1977; Jenkins, 1977;

Pylyshyn, 1973) have objected to the heavy theoretical burden

imposed upon such terms. The problem is that often the essentially

metaphorical use of these concepts can give rise to misleading

implications. For example, we ordinarily talk about mental

representations being stored in memory, searched for, and retrieved.

It is easy to see how, if taken literally, such ideas can lead to

the conclusion that people's heads are populated with a huge number

of pre-packaged permanent structures corresponding to everything

they know. We will refer to the view that postulates permanent

knowledge structures as the "structural" approach and to the

alternative view, that treats mental phenomena as resulting from

transient patterns directly created by the functioning of the

biological hardware, as the "biofunctional" approach.

Not only does the biofunctional approach differ from the

structural approach in its rejection of long-term mental structures,

but it also differs in the way it views the dynamic aspect of

cognition. The structural view deals with the dynamic aspects of

the mind in terms of searches for and changes to permanently-stored

knowledge structures. Since we question the need to postulate such

structures, we try to avoid this way of dealing with the problem: If

there are no permanent cognitive structures, then they cannot be

found or changed. In biofunctional terms, cognitive patterns are

viewed as transient dynamic structures. In short, along with

Bartlett, Bransford and his colleagues (e.g., Bransford, Nitsch &

Franks, 1977), and Dennett (1983), we argue that cognition does not

involve the selection of pre-existing cognitive structures, rather

it involves the creation and re-creation of transient ones. We wish

to emphasize, however, that our arguments against the use of

structural concepts must not be interpreted as an attempt to free

all psychological exposition from structural terms. As Freeman

(1975) points out, even at the more concrete levels of exposition

"it is reasonable and perhaps necessary to describe the

manipulations of the central state with concepts that are both

generalized and familiar from common experience . . . [although]

. . . there is not and cannot be an a priori relation between those

concepts and the dynamics of the central neural mechanisms" (p.

414). Our view is that as long as the prevailing theoretical

context clarifies the meaning of "structural" terms, their use

should cause no problems. When, on the other hand, the terminology

itself determines the underlying theoretical context, as is

sometimes the case when long-term memory metaphors are used, we

believe an inappropriate picture of the nature of mental functioning

arises.

Over the years cognitive psychologists have gathered a great
deal of empirical data that seem to support various aspects of the
structural approach. However, there is also a great deal of
indirect evidence in the neuroscientific literature that contradicts
it (see, e.g., Freeman, 1975; Uttal, 1978). While there is
currently no direct psychological evidence supporting a
biofunctional approach (for a discussion of some indirect evidence,
see Schallert, 1982; Shanklin, 1981), the major assumption that
differentiates the structural and the biofunctional perspectives
(i.e., mental structures are transient biofunctional patterns) is
shared by many currei psychobiologists and neuroscientists (see
Edelman, 1978; Freeman, 1975; John, 1967, 1972; Katchalsky, Rowland
& Blumenthal, 1974; Uttal, 1978).

Our account of cognition attempts to bridge the conceptual gap
that results from the absence of a common language between cognitive
psychology and neurophysiology. Although one might think that
compatibility of psychological theories with what is known about the
human nervous system is an obvious minimal requirement, such
compatibility is frequently conspicuously absent. For example,
Schmitt (1978) noted that "many theories of higher brain function
(learning, memory, perception, self-awareness, consciousness) have
been proposed; but in general they lack cogency with respect to
established anatomical and physiological facts and are without
biophysical and biochemical plausibility" (p. 1). Similarly,
Gallistel (1980) in discussing a psychological model of the control
of limb movement (Adams, 1977) claims that modern neurophysiological

work on the mechanisms of co-ordination renders the theory

untenable. The mess; e is clear: psychologists need to attend more

closely to neuroscientific research.

The problem as it relates to psychological research, therefore,

does not seem to be the absence of biologically plausible theories.

Such theories exist in the work of authors like Donchin (1981),

Freeman (e.g., 1975), Grossberg (e.g., 1982), John (e.g., John,

1972; John & Schwartz, 1978), Maturana (1978), O'Keefe and Nadel

(1978, 1979), and Uttal (1978). Rather, in some subtle way, the

problem seems to relate to the deep-seatedness of the influence of

the structural paradigm on cognitive psychology. The structural

bias, we believe, has drawn attention away from existing

neuroscientific theories many of which are in essence biofunctional.

For instance, Jenkins (1981) noted that structural psychology

frequently cites William James' treatment of habit formation and

ignores his "true functionalism."

The view we are proposing is based on theoretical constructs at

three interacting levels: (a) the (neuroanatomic) micro-,

organizational level, (b) the biofunctional macro-organizational

level, and (c) the psychological level. At the micro-organizational

level, we will attempt to characterize a physically unitary and

functionally autonomous microsystem as the most elementary

biofunctional unit. Consistent with the current trend in

neurophysiology, we will assume that neural microsystems correspond

to neurons, and will often refer to them as (neuronal) elements. At

the macro-organizational level, we will attempt to characterize what

we refer to as _macroactive structures_. These are patterns of
activity resulting from simultaneous functioning of physically
distributed elements. Following Freeman (1975), we will refer to
the totality of active elements in the nervous system as the _mass
action system_. Finally, at the mental level, we will attempt to
characterize the central concept in the biofunctional model, namely
what we call the _schema-of-the-moment_. This is a transient mental
structure that arises from activity in the mass action system. We
use the term _schema-of-the-moment_ for two main reasons. First, we
argue that it is in terms of this "functioning mass of the moment,"
as Bartlett (1932) and Head (1920) called it, that all cognitive
phenomena (comprehension, learning, remembering, awareness,
attention, etc.) take place. Second, the schema-of-the-moment is
assumed to be the only mental pattern in existence in a given
individual at a particular time--everything else is neuroanatomic or
neurophysiological.

The discussions in this paper are organized in three main
sections around the notion of the schema-of-the-moment. The first
discusses a number of important background questions including that
of how it might be possible for widely distributed elements to
intercommunicate. The second section discusses the pre-subjective
foundations of the schema-of-the-moment. Exactly what neuronal
microsystems are, how they function, how they generate psychological
qualities, how they are distributed, and how they functionally
relate to one another. In the third section we describe the main
characteristics and functions of the schema-of-the-moment.

The Schema-of-the-Moment: Some Preliminary Issues

The Foundations of the Structural View

There are two fundamental assumptions upon which the structural
view of cognition is based. One is that mental life can be
characterized in terms of various kinds of cognitive processes. The
other is that these processes are performed on long-term knowledge
representations. Neither of these assumptions are part of the
biofunctional view.

Most structural theories (e.g., schema theories) assume that
the dynamic aspects of cognition can be accommodated in information
processing terms. For example, the schema selection process is
assumed to be the result of some kind of search or retrieval
mechanism. The central concept employed in information processing
models to capture the dynamic (i.e., the processing) aspect is that
of an input-transformation-output sequence--the system accepts
inputs either from memory or from outside, performs transformations
on them, and produces resultant outputs, that get stored in memory
or are manifested in verbal or nonverbal behavior.[1] The inputs and
outputs themselves are essentially static. Typically, they are
knowledge representations--data structures that exist independently
of the dynamic component. In general, information processing models
are concerned with "what happens to information about a stimulus
from the 'real world' as it passes through the system" (Klatzky,
1975, p. 11).

We believe that many of the questions addressed by information
processing theories arise only as a result of the assumption that

the "objects" of processing possess some independent existential

status. In the biofunctional model, the system is dynamic but it

does not process anything; there is no object of processing.

Knowledge is considered to be a transient phenomenon created and

re-created by the functioning of the biological hardware. What is

created lasts only while the underlying biological system that

creates it continues to be active. Nothing nonbiological is stored,

and apart from its potential to be re-recreated, knowledge has no

permanent existence.

An analogy based on the functioning of the endocrine glandular

system may serve to clarify the contrast between the re-creation and

input-transformation-output views. There is a group of cells

located in the cortical part of the adrenal glands. These cells,

when activated, produce the hormone, cortisol. The cells themselves

get activated by another hormone, ACTH (adrenocorticotropic

hormone), released in the anterior part of the pituitary gland. The

crucial point is that there is absolutely no input-transformation-

output relationship between the stimulator ACTH and the produced

cortisol. Adrenal cortical cells, once activated, create the

cortisol through, for example, biochemical operations based on

substances other than those contained in ACTH. It is this

dissociation between the input and the output--mediated by the

intrinsic functional properties of the specialized organismic

system--that renders any system-independent ACTH-to-cortisol

transformation rules, or any precise formal description of the

product based on them, inappropriate. The qualitative properties of

the output are determined entirely by the biofunctional properties

of the specialized cells in the adrenal glands, even though there

may sometimes be a (linear or nonlinear) quantitative relation

between the input and the output. This qualitative dissociation

between the input and the output means that, in principle, cortisol

can be produced in the total absence of ACTH, and that cortisol

might fail to be produced in the presence of ACTH. In much the same

way, neuronal mechanisms active at a given time combine functionally

to create a transient cognitive structure. Such a dynamic

functional organization is input-independent in the sense that there

exists a qualitative dissociation between the characteristics

inherent in the external stimulation and the functional properties

of the neuronal system. Conceptualizing the dynamic aspect of

cognition in this way eliminates the need to postulate the

preservation of long-term knowledge structures.

Ironically, Bartlett (1932), who is often cited in the context

of structural views of cognition (especially with respect to schema

theory), was strongly opposed to the idea of long-term mental

representations and favored some kind of functional account. He

made this point explicitly when he stated that his approach was

based on the "study of the conditions of organic and mental

functions, rather than ... [on] an analysis of mental structures"

and that "it was ... the latter standpoint which developed the

traditional principles of association" (p. 304). Our distinction

between structure and function is similar to that made by Bartlett.

He believed that a functional approach was necessary to explain a

number of observations that puzzled him. For example, he found it

curious that although incoming information is learned only if it is

incorporated into what he called the "organized mass of the moment,"

later recollections of such information, in recall or in thinking,

do not always occur "en masse." What happens to the strong tie

established between the input information and the schema in terms of

which it was learned? According to Bartlett, "In remembering, we

appear to be dominated by particular past events," as opposed to

past schemata in their intact original form. He stated that what

was once an "active organized setting looks as if it has somehow

undergone a change, making it possible for parts of it which are

remote in time to have a leading role to play" (p. 202). He was

also puzzled by the fact that incoming information is learned in a

chronological sequence in which every new item is strongly

influenced by the one before it. However, later recall of an item

does not seem to favor recitation of the entire sequence and would

be highly inefficient and inappropriate if it did (see p. 219).

Thus, Bartlett concluded that thinking, for instance, is only

"possible when a way has been found of breaking up the 'massed'

influence of past stimuli and situations, only when a device has

already been discovered for conquering the sequential tyranny of

past reactions" (p. 225). This, according to Bartlett, would be

possible if schema relations were conceived of as transient (i.e.,

functional) relations.

Bartlett also favored the functional approach over the

structural approach because he found unacceptable the idea that in

an associative structure each element "retains its essential

individuality." He preferred to think of elements as combining into

an organized mass.   In an organized mass, the components are not

related by association.   Rather, each element loses its identity and

becomes an integrated part of the combination in the same way that,

when oxygen and hydrogen combine to produce water, the properties of

these elements are no longer evident.   Furthermore, the resultant

structure comes to possess emergent properties that are not present

in any of the component elements in the same way that water

possesses properties not possessed by its component elements.

Thus, far from taking mental structures as given, Bartlett was

concerned with two complementary problems: how elements combine into

a schema, and how schema elements manage to free themselves from the

shackles of past combinations (i.e., how they "re-individualize"

themselves).   While he apparently believed that this was possible

only if schema elements, when combining, entered into functional

relations, he could not decide what sort of elements would make this

possible, reluctantly picking the image as his candidate.   His

reluctance seems to have been based in part on a realization that

images are overly subjective and insufficiently biological (see p.

220).   Images are themselves cognitive structures, and Bartlett

apparently felt that they lacked the appropriate combinatorial

properties that the true elements in a functioning system would

require.   Our solution, to be discussed later, is to specify, at the

pre-subjective neuronal level, elements that are biofunctionally

(and, only by extrapolation, psychologically) primitive.

Mental Relations and Brain Connections

Once the notion of long-term cognitive structures is abandoned,
the question arises as to the relation between the neuroanatomic
network and the cognitive organization. In particular, it becomes
necessary to consider the extent to which, if any, there is
structural conformity between the two systems. Minsky (1980) and
Norman (1980) draw attention to the problem of specifying this
relation and refer to it as the "crossbar" and "address" problem
respectively. According to Minsky, "this problem confronts every
brain theory that tries to explain how the mind is capable of any
great range of 'associations'" (p. 124). According to Norman,
"associations among memory concepts . . . [imply] much too much
knowledge of the wire (or of its biological equivalent) that is to
snake its way among the already existing stuff" (p. 22).

In theory, there are at least three types of solutions all of
which have been proposed at one time or another. The first
possibility is to postulate a particular (pre-existing or, rather,
pre-functional) neuroanatomic pattern, partial or complete,
corresponding to every cognitive pattern. This essentially amounts
to mapping the structural cognitive network into an isomorphic
neuroanatomic network. Such isomorphism was a major
psychobiological premise in Gestalt psychology (see Uttal, 1978 for
a discussion of this). Isomorphism is also implicit in the
connectionist approach to neural modeling of semantic networks,
whether these models represent concepts as particular hardware units

(Feldman, 1979, 1981; Fahlman, 1981) or as patterns of activity in
localized cell assemblies (Hinton, 1981).

The second possibility is that the neuronal network is
analogous to some sort of sophisticated telephone network. By
allowing directional hard-wired routes between elements, the nervous
system would somehow generate two-unit or multi-unit (transient)
communication patterns. A telephone network is directional because
the initiating unit must know the "address" of the target unit(s).
Directional connectionist models imply "that 'remembering' requires
the discharge of those particular cells which constitute the new
line, and those of the cells to which the line is directed" (John,
1972). John and his colleagues (e.g., John, 1967, 1972; John &
Schwartz, 1978; Thatcher & John, 1977) have been among the most
outspoken critics of connectionist models, arguing that, for
example, responses to even the most elementary stimuli (e.g., a
flash of light or a click) are made by cells distributed throughout
the brain and that a given cell participates in many functional
patterns. Although few psychologists and neuroscientists still
subscribe to the type of connectionism that John criticized,
connectionism in some form or another is still widely embraced (see,
for example, the essays in Hinton & Anderson, 1981). It is now
generally recognized that mental relations are variable. But modern
connectionists attempt to accommodate such variability in terms of
synaptic plasticity. As Uttal (1978) has convincingly argued, the
large conceptual gap between synaptic plasticity (defined in terms
of synaptic weights, facilitation levels, etc.) and complex mental

phenomena renders synaptic connectionism implausible (pp. 540-541)..

Another line of argument against connectionist models comes
from recent developments in theoretical chemistry and their
application to activity in masses of neurons (Freeman, 1975;
Katchalsky et al. 1974). The thrust of the argument, which is
incidentally highly reminiscent of Bartlett's criticism of
associative connectionism cited earlier, is that neural activity,
far from occurring in terms of independent hardware units joined by
neuroanatomic connections, tends towards organization and self-
consistency in a fashion analogous to that occurring in diffusion-
coupled chemical reactions. According to Freeman (1975), these
ideas "lead to expectations of neural activity quite different from
the discrete characteristics of activity in networks" (p. 8).
Freeman claims that given this perspective, what emerges "from the
study of neural mass action is not merely an extension of current
understanding; it is revolutionary in the sense defined by Kuhn
(1970)" (p. 8).

Incidentally, it must be noted that anticonnectionists do not
reject the existence of precise neuroanatomic connections. Rather,
they maintain that although precise neural connections exist at the
anatomic level, it is necessary to distinguish between anatomical
connections and functional relations, and that a set or
constellation of neurons having fixed anatomical connections may
admit of many functional patterns (Freeman, 1975).

If synaptic plasticity or modifiability does indeed fail to
adequately explain functional connections among elements, the

nervous system must accommodate variable functional relations among elements in some other way. The fact that neuronal elements are capable of interacting with other distant neuronal elements that are distributed throughout the brain suggests that there might exist within the nervous system some sort of relational medium to make such interaction-at-a-distance possible. The third possibility, therefore, and the one we find most plausible, is that in addition to synaptic modifiability, the neuronal network also communicates through an all-spreading nondirectional relational medium. Such a medium would allow (within amplitude, etc., constraints) nondirectional conductance of electrical or chemical energy (signals) in addition to directional element-to-element interactions.

In a totally nondirectional network every signal can potentially reach all specialized units and no signal is aimed at any particular unit directly. Thus, the initiating unit does not need to know the address of the target unit. Rather, target units are specialized to get activated in response to (or "to recognize") the functioning of the initiating unit that produces the signal, and to remain indifferent to the functioning (and, thereby, to the signal) of any other. Particularly relevant examples of specialized systems functioning in a nondirectional environment are the auditory and visual systems of animals. While both of these mechanisms function in the same environment--filled with sound and light waves--the ears respond to sounds but are deaf to light while the eyes perceive light but are blind to sounds. One can imagine a

similar principle to holds for the neural network. In other words,
it is possible that neuronal elements interact, not merely because
source elements are connected or have the addresses (or phone
numbers) of target elements, but because the elements themselves are
uniquely specialized. This specialization permits target elements
to "hear" impulse patterns that spread, like sound waves, throughout
the neural network if those patterns happen to be signals in their
"language." We believe this shift of "responsibility" from source
units to target units solves the problem of address. Thus, in this
particular sense, the act of communication is more like a (radio)
broadcast than a (phone) call because in a broadcast the source unit
emits the signal indiscriminately whereas in a phone call a decision
must be made as to who is going to receive the call and the phone
number of the target unit must be known.

The assumption of non-directional communication among neuronal
elements critically depends on the nature of localization and
distribution in the nervous system. By localization we mean that
specialized elements that are functionally highly selective are
fixed with respect to their physical location. Distribution, on the
other hand, means that the elements that are simultaneously
functioning can be physically widely spread apart. Thus, not only
does the nondirectional hypothesis solve the problem of address but
it also resolves the apparent incompatibility between localization
and distribution. Early distributed models were explicitly
nonlocalizationist. Lashley's (1950) original formulation of
distribution stated that "the same neurons which retain the memory

traces of one experience must also participate in countless other

activities" (p. 479). Somehow every neuron learnec (or stored)

everything that many other neurons learned. Nonlocalized storage is

also an assumption in holographic models of distributed memory

(Pribram, 1981; Wess & Roder, 1977). However, evidence gathered by

Hubel and Wiesel (1959; 1962, 1965) and others has shown that the

brain is not a homogeneous mass. Whereas traditional models of

distributed memory considered localization and distribution to be

antithetical, more recent evidence suggests that distribution and

localization are not incompatible (e.g., Freeman, 1975; John &

Killam, 1960; John & Schwartz, 1978; Uttal, 1978). For instance,

Freeman argued that "the behavior of animals depends both on the

properties of neurons and on the ways in which they are _functionally_

connected or interconnected" (Freeman, 1975, p. 4, italics added).

Similarly, Uttal (1978) pointed out that while one must "emphasize

the concept of interacting systems and the premise of nonunique

localization of each psychological function . . . it also appears

that there is a considerable degree of differentiation of function

of the various areas of the brain and the brain stem; that is, they

are not equipotential" (p. 354). Variable functional relations

among interacting systems can be accommodated by a system consisting

of specialized units that can communicate in terms of a

nondirectional, all-spreading environment.

We have hypothesized an all-spreading medium in order to

clarify, at least conceptually, the problem of interaction-at-a-

distance in a mass action system with distributed elements. An

all-spreading environment, however, does not mean that electrical or
chemical conductance takes place in a vacuum, even though some sort
of extracellular propagation may play an important role (see
Nicholson, 1979). Neither does it mean nonspecificity or
imprecision in the pattern of actual neural connections. The neural
network as a whole may serve as a common network.

The two types of physical relational vehicles (directional and
non-directional) may be illustrated by an analogy to the functioning
of exocrine and endocrine glandular systems. Exocrine glands (e.g.,
the salivary glands) release their products into specific ducts
which direct them to target organ These would cc   nd to
directional element-to-element (neuroanatomic) connections.
Endocrine glands, on the other hand, secrete their products into the
extracellular fluid surrounding capillaries. The hormones they
produce enter the blood circulation system, which is itself an all-
spreading environment. This makes it possible, for example, for the
ACTH released in the anterior pituitary gland, located on the lower
surface of the brain, to stimulate (activate) cortical adrenal cells
located above the kidneys. It is conceivable, in principle, that a
direct point-to-point duct could have been physically available to
carry ACTH from the pituitary to the adrenal glands. However, if a
tube were to be available from every endocrine gland to its target
organ, organisms would become monstrously complex. Instead, ACTH
enters the blood circulation system. This, of course, takes the
hormone to other irrelevant organs as well (hence, all-spreading and
nondirectional), but it is also sure to reach the adrenal cells

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which are specialized to get activated by it, because these cells like everything else are connected to the blood circulation network.

The possibility that the nervous system is also, in part, an all-spreading environment analogous to the blood circulation system cannot be ruled out. As early as the, 1920's, Paul Weiss argued against the connectionist view and concluded, based on the then existing evidence, that "the central nervous system and the non-nervous periphery entertain their mutual correspondence by means of some sort of sending-receiving mechanism, specific for each individual muscle." According to this view, the central nervous system is "endowed with the capacity for discharging as many different modes or forms of impulses as there are different muscles in the limb." There is a specific impulse for every muscle receptor. Every muscle receptor, on the other hand, "would possess the power to respond selectively" to its proper impulse. Consequently, if "the central impulses for a limb muscle were circularized in the whole limb" the mechanism of selectivity of function "would ensure that every call be answered by the correct muscle, even though the latter may have been displaced, re-innervated by strange nerves, and prevented from sending informative messages back to the centers" (Weiss, 1936, pp. 511-512). Weiss's resonance principle is no longer generally accepted by developmental neuroscientists, but we believe his ideas concerning indiscriminate synaptic connectivity, successfully challenged by Sperry and his associates (see Attardi & Sperry, 1960, 1963; Meyer & Sperry, 1976), must be distinguished

from his suggestive element-impulse specificity hypothesis, which
has yet to be directly tested.

An all-spreading functional environment implies that,
regardless of its place of origin in the nervous system, the signal
that a given functional pattern generates can stimulate elements
that "recognize" it wherever they may be located in the nervous
system. There are definite indications that this may be the case.
Consider a letter recognition (identification) task. Images
ordinarily begin on the retina and presumably stimulate
corresponding centers or elements somewhere in the brain. It is
conceivable that specific "image-to-center" connections as well as
long-term graphemic patterns could mediate recognition. However,
recognition need not depend on particular hard-wired connections or
on pre-existing long-term associations. Blindfolded subjects are
capable of correctly identifying letters "finger-written" on their
skin. White, Saunders, Scadden, Bach-Y-Rita, and Collins (1970)
used a visual substitution apparatus which converted optical images
into tactile displays which blind or blindfolded subjects were able
to "see with their skin." It was shown that "subjects are able to
perceive certain simple displays . . . almost as soon as they have
been introduced" (p. 23) and that with minimal amounts of training
they are able "to identify familiar objects and to describe their
arrangement in depth" (p. 25).

The hypothesis of functional communication between
distinctively specialized neuronal elements also finds support in
the evidence that the re-establishment of original functional

relations is possible even after specialized cells are surgically

removed from their original site and are regrown at a different part

of the body. If a piece of skin is removed from the belly region of

a salamander and planted on its back and if, after regeneration,

this skin, now on the back, is stimulated, the animal proceeds to

scratch its belly, the original site. Such seemingly maladaptive

responses, extensively studied by Sperry and others, are often

discussed in the light of the nature/nurture issue (see, e.g., Rose,

1976). However, more basic than whether something is innate or

acquired is the problem of how it works. One may simply assume that

regeneration only connects the pre-specialized skin receptor cells

to an all-spreading neural network. There is no need for the re-

establishment of particular nerve fibers to wind their path, through

some mysterious innate guiding mechanism, all the way to the related

central cells. Once specialized receptor cells are merely connected

to the neural network (or perhaps to the particular brain region),

they can activate the individual target cells through generation of

unique energy patterns. The energy patterns, generated by the

central cells can, in turn, activate the muscles involved in the

scratching of the belly. Because the belly receptor cells function

in the same unique fashion regardless of where they are located, and

because this functioning is recognized by the related central cells

as "belly" stimulation, the animal responds maladaptively. Sperry

(e.g., 1943) explained these results "in terms of re-establishment

of specific anatomical associations rather than in terms of specific

nerve energy and resonance phenomena." But he also emphasized that

"the latter possibility is by no means excluded" (p. 47). In fact,

it is still not clear that a resolution between Sperry's directional

connectionism and Weiss' element-impulse specificity model has yet

been achieved (see Meyer & Sperry, 1976; Sperry, 1966; Wall, 1966;

Weiss, 1966). As Wall (1966) argued, "the so-called specificity of

neuronal function . . . may mean that specificity of function can

be attained without a microscopic determination of the exact

morphological structure of some parts of the nervous system"

(p. 230).

Given the concept of an all-spreading relational vehicle, the

most efficient way of relating the cognitive system and the neuronal

system seems to be to assume that (a) the cognitive system is

comprised of transient functional relations, and that (b) that

post-functional patterns are independent of any isomorphic pre-

functional neural associations. Independence of post-functional

(mental) relations also resolves Minsky's crossbar problem. As

Minsky (1980) put it "if the mechanisms of thought can be divided

into specialists that intercommunicate only sparsely, then the

crossbar problem may need no general solution. For then, most pairs

of agents will have no real need to talk to one another; indeed,

since they speak . . . different languages, they could not even

understand each other" (p.125). And, to continue the metaphor, if

they can understand each other, they will do so regardless of where

they are located or whether they are connected directly so long as

they can "hear" each other (i.e., so long as they are part of the

overall neural network).

Pre-Subjective Foundations of the Schema-of-the-Moment

This section discusses some key assumptions pertaining to the
microbiofunctional and macrobiofunctional properties of the brain in
an attempt to show how these properties can explain the pre-
subjective foundations of the schema-of-the-moment. These
assumptions, while speculative in detail, are generally compatible
with existing neurophysiological literature bearing on localized and
distributed functional properties of the nervous system. For
clarity of exposition, we shall not interrupt to substantiate every
claim or to discuss the controversies that might be involved. The
interested reader is encouraged to consult Freeman (1975, Chapter 1)
on the nature of dynamic patterns, Hubel and Wiesel (1980) on
localization in the primary visual cortex, Lynch (1980) on
distribution of function in the posterior parietal cortex,
Selverston (1980) on the central pattern generators underlying
rhythmic behavior, O'Keefe and Nadel (1979) on localization of
"place-coded" neurons in the hippocampus, Puccetti and Dykes (1978)
on the problem of accounting for qualitative differences between
subjective experiences of touch, hearing, and vision, and Uttal
(1978) on the role of microscopic and macroscopic structures in the
formation of dynamic representations.

Are Pre-Existing Long-Term Patterns Necessary?

As we have said, current approaches to cognition and
comprehension presuppose the existence of long-term relatively
static knowledge representations that underlie cognitive
functioning. One motivation for hypothesizing long-term mental

structures is the fact that ideas seem to come to mind (to be

recalled, etc.) together, or in relation to one another. It is then

assumed that they stay together in some cognitive warehouse, even

when they are not operative. Thus, the structural approach

maintains that ideas are related before they become active, and that

remembering involves activation of static knowledge representations.

By contrast, from the biofunctional perspective, there are no

pre-existing mental patterns. Cognitive relations are established

only after distributed neuronal elements become active, Like

chemical elements, neuronal elements have properties that determine

their combinatorial potentials. Only when two or more elements with

appropriate combinatorial properties (see the section on types of

combinatorial relations below) are in a state of simultaneous

functioning do they combine to generate a cognitive pattern.

Consider, as another analogy, a collection of colored lightbulbs.

When a subset of them is on, a unique pattern of light and color is

generated. It does not matter whether individual bulbs are

physically connected or when each bulb goes on. The characteristics

of the pattern are determined by the participating elements and not

by how the bulbs are connected physically or by the history of their

participation. A given pattern could result from a long sequence of

events in which some bulbs would go on and some would go off. Once

some or all of the bulbs go off, the particular pattern no longer

exists.

Similarly, a constellation of active neuronal elements

generates an idea or concept as the component elements combine into

a biofunctional pattern. This can be illustrated in terms of what

might happen when a word like dog is understood after it is heard.

Hearing the word activates a constellation of independent neuronal

elements. This happens, not because the elements are preconnected

as a neuroanatomic pattern, but because the stimulus itself (in this

case the pattern of sound waves that reach the ear) has independent

signal components that activate each of the independent elements of

a constellation--elements that can be physically distributed

throughout the brain. Once the elements are active, they combine

into a biofunctional pattern and, in doing so, they generate the

concept corresponding to the word. This notion can be clarified in

terms of another analogy. When a handful of pebbles is thrown into

a pond, each pebble hits the water at a different spot and creates a

wave pattern. Then, the wave patterns of all the pebbles combine to

form a global pattern of waves. This global pattern, which results

from the combined effects of the individual pebbles, corresponds to

the dynamic pattern created by the active elements of the

constellation underlying a concept. The concept will arise in the

psychological experience of the moment whenever the particular

elements that produce it change their activity, functioning as a

coherent combination. It does not matter how each element comes to

be active (i.e., one at a time, all at once, etc.) or what causes

them to be active (the sight of the word, the sound of the word, a

dog, etc.). In fact, according to this view, elements that create a

particular concept can come to be active as a result of the

combination of elements from two or more unrelated constellations

whose corresponding concepts have no apparent relation to one

another. In sum, while in a structural pattern, it is the long-term
"relations among elements that counts" (Piaget, 1970, p. 9), for a
functional pattern what counts is the elements themselves--their
characteristics, how they function, and how they functionally
combine.

Neuronal Elements as Biofunctional Microsystems

The model we are proposing places a heavy theoretical burden on
the notion of neuronal elements. It is, therefore, necessary to
specify exactly what sorts of biofunctional properties these
elements should have in order to combine into macroactive structures
and in order to generate subjective experiences with sufficient
qualitative diversity.

While there is general agreement that mental structures are
complex and that they consist of more elementary components, there
is less agreement as to what these components, or elements, are.
Depending on the situation or level of analysis, theorists have used
semantic features, perceptual features, images, ideas, etc. as
primitive units of analysis. However, in an approach such as
Bartlett's or ours, where it is critical that the elements be
capable of combining while remaining, in principle,
individualizable, the choice of an appropriate standard element is
much more constrained. The biofunctional model assumes that the
most elementary theoretical construct is a physically unitary
(although not physically elemental) and functionally autonomous
microsystem. The assumption that the elements are physically
unitary systems means that they are taken to be neurophysiological

"atoms." The assumption that the elements are functionally

autonomous is compatible with their being viewed as cognitive

"atoms." In other words, we view these elements as being the most

elementary biofunctional units in the nervous system and the locus

of the link between the mind and the brain.

It is important to point out that our use of the term neuronal

element is not meant to imply that single neurons actually represent

mental structures. Traditionally, such concepts as pontifical

neurons (Fessard, 1954; Sherrington, 1947), cardinal cells (Barlow,

1969), command neurons (Wiersma & Ikeda, 1964), and feature

detectors (Hubel & Wiesel, 1980) have been postulated to represent

complex psychological patterns. In contrast to these views, we

assume that mental structures are "molecular" rather than "atomic";

more than one neuronal element must be involved in the creation of

any mental entity. In other words, individual neuronal elements do

not represent mental structures (i.e., features, images, etc.); only

distributed constellations of them do.

The claim that it is distributed constellations of neurons, and

not individual ones, that are responsible for the creation of

cognitive structures could be interpreted as meaning that individual

neuronal elements are equipotential. This is certainly not our

view. Rather, like atoms of particular simple substances, neuronal

microsystems are assumed to have unique functional properties. As

with chemical elements, these properties constrain the types of

combinations in which an element can participate, and they constrain

the conditions under which such participation can occur. However,

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within these constraints, a particular element can participate in an

indefinite number of combinations.

The biofunctional perspective also means that the neurons are

not equipotential in the sense used by nonlocalization theorists

such as Lashley. While in the biofunctional model, each neuronal

element can be considered a "memory," or rather a "potential memory"

element, it is not assumed that neurons retain memory traces; in

particular it is not necessary to assume that neurons retain memory

traces for a large number of experiences and behaviors (Lashley,

1950, p. 479). Such a claim would make the activity of neurons

completely dependent on past traces by implying that they could only

participate in combinations they already had traces for, and that

they would only respond to stimuli for which they had a matching

trace. In the biofunctional model, past experiences are re-created

because the same constellations of elements recur, not because

something is stored in each element. The system is completely

generative, creating new experiences entirely through new

combinations. At the micro-organizational level, each element is

physically located in some area of the brain. However, since the

elements can functionally coact or interact at a distance through an

all-spreading medium, the system can also be fully distributed.

At the macro-organizational level, the totality of active

neuronal elements constitutes a mass action system (Freeman 1975).

In recent years, the nature of macroactivity in the nervous system

has been the subject of an interesting new theoretical approach

derived from the field of dynamics (Freeman, 1975; Katchalsky,

Rowland & Blumenthal, 1974; Prigogine & Nicholis, 1971; Kugler,

Kelso & Turvey, 1980). According to this view, macroactive

structures are dynamic patterns that (a) consist of discrete

elements, (b) are self-organizing, and (c) consume energy to

maintain stability (see, e.g., Freeman, 1975). Katchalsky and his

colleagues, who pioneered the work in this area, state that one

possible consequence of "considering discrete systems embedded in a

continuous system would be the subordination of obvious structural

discreteness to a functional one: the spatially discrete elements

could be brought to functional continuity . . . or the structurally

continuous medium to functional (dynamic) discontinuity" (Rowland,

reported in Katchalsky, Rowland & Blumenthal 1974, p. 78). Clearly,

the biofunctional model is compatible with these views. Rewording

the Katchalsky et. al. quotation in terms of the present view: one

advantage of considering neuronal microsystems embedded in dynamic

macroactive structures that they themselves create would be the

subordination of the microsystems to their overall functional

organization. A constellation of physically unitary microsystems

could be brought to functional continuity or the continuous

macroactive organization can be subordinated to the independent

functioning of individual microsystems. It seems to us that it was

shifts of this sort in the relative subordination of individual

components to the global structure and vice versa, that Bartlett

(1932) deemed necessary in mental functioning when he argued that

not only must individual elements combine into an organized mass but

that after they do, they must once again be individualizable in the

context of the global structure.

Microsystems as Elementary Loci of Psychological Qualities

It seems to us that the key to bridging the gap between cognitive psychology and the neurosciences lies in the specification of the manner in which the nervous system might generate qualitatively diverse psychological experiences. Concern for this problem does not seem to be a characteristic of current practice in cognitive psychology, which tends to focus on unconscious mental structures and processes. However, there has been some concern with this issue in the neurosciences (see e.g., Eccles, 1953; Sperry, 1952, 1969, 1977). Recently, the problem has been brought into sharp focus by Puccetti and Dykes (1978) who emphasized the apparent structural (cytotechtonic) similarity of the primary visual, auditory, and somesthetic sensory areas. Noting that these similarities afford little opportunity for explaining differences in subjective quality, they concluded that "not only is present-day neuroscience unable to account for the subjective differences [between vision, hearing, and touch] in terms of discrete neural mechanisms, but there is no good indication that it ever will be able to do so" (p. 337). While some of the commentators did not find Puccetti and Dykes' conclusions very convincing, others agreed with their assessment of the state of the art. For example, Szentagothai (1978) went so far as to say that "the spectacular developments in the last quarter of a century . . have widened . . . the gulf between the brain and the mind" (p. 367).

Our views on subjective quality are in general agreement with those advanced over the years by Sperry (e.g., 1952, 1976, 1977),

who claimed (a) that subjective qualities emerge from the activity

of the brain, and (b) that these qualities, in turn, exert a causal

influence on brain activity. However, in searching for an

appropriate level of analysis to explain the causes of subjective

qualities, Sperry (1978) excluded the microbiofunctional level and

argued that "it is our bet that [the proper level] is not at the

atomic, molecular, cellular, or nerve-relay levels, nor even at the

sensory cortical levels, but rather, at a somewhat higher level that

involves . . . centralized adjustments of the brain as a unit"

(p. 366). In this respect, we disagree with Sperry. While Sperry's

theory might account for the undifferentiated conscious experience

(i.e., global awareness), we believe it fails to explain finer

qualitative discriminations (i.e., focal awareness). By fixing the

locus of subjective quality at the level of neuronal microsystems,

the biofunctional model can not only account for people's competence

in making fine subjective discriminations (by individualizing

components of the whole), but can also explain global differences in

subjective experiences (because microsystems can combine into

macrobiofunctional organizations that involve the activity of the

entire brain).

In order to demonstrate how psychological qualities can arise

as a consequence of macroactivity in distributed constellations of

elements, we must take a closer look at the key concepts of

specialization, constellation, and combination. In order to

understand what we mean by element specialization, it may be helpful

to again use the lightbulb analogy. Let us suppose that our array

of lightbulbs contains two broad categories of bulbs, namely,
colored and uncolored ones. We will call the colored bulbs
"specialized elements." The uncolored bulbs we will call "raw
elements," implying that they can become specialized by getting
painted a particular color. In this array, each bulb can "perform"
a few feats always in the same unique fashion: it can go on or off,
it can become brighter or dimmer, and if it is not already
specialized it can become so. Similarly (and now we are out of the
analogy), the neuronal network can be assumed to consist of a great
number of elements, each of which is or can become specialized and
each of which can get activated or inhibited. In addition, each
specialized element can (a) change its rate of activity, (b) produce
a unique pattern of energy (i.e., a signal), (c) initiate
functioning consistently in the presence of some unique pattern of
internal or external energy (i.e., a signal), and (d) generate, when
functioning, a unique feeling of awareness. In this sense, a
specialized element is a discrete unit with quite specific but very
limited properties. This assumption is consistent with the view
that "neurons, in the course of differentiation and development and
in processing of information over the span of the organism's
lifetime, develop unique identities: genetically and experientially
determined individualities" (Schmitt, 1970, p. 208), and it is also
consistent with the evidence that the relative number of highly
specific cells seems to vary drastically with experience (Imbert &
Buisseret, 1975).

When two or more specialized elements function simultaneously
they can combine to create a macroactive organization or combination
(see the section on types of combinatorial relations below). To
emphasize the physical distribution of elements participating in a
combination, we refer to the physical counterpart of a combination
as a constellation. Constellations differ from elements in several
respects. First, unlike elements, they cannot be considered
specialized. This is because they contain autonomous elements which
can participate in other constellations. Second, elements are
assumed to be localized and physically unitary while constellations
can have elements scattered throughout the nervous system. Third,
while individual elements possess element-specific biofunctional
properties that theoretically are unambiguously traceable to some
unitary physical entity--the element itself, constellations have
nonspecific (i.e., emergent) properties which result from the
functional combination of the elements involved and which cannot be
traced to any unitary physical entity because they are different
from those possessed by any one of the participating elements.

The notion of combination encompasses four major biofunctional
aspects that result from the activity of the corresponding
constellation. First, combination is the establishment of a
transient dynamic pattern involving anatomically distributed
elements--the combinatorial aspect. Second, combination involves
the merging of element-specific energy patterns resulting in
nonspecific (i.e., emergent) energy patterns (i.e., signals)--the
relational aspect. In the case of energy, pattern combinations can

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be conceptualized in terms of interference patterns (Lashley 1950).

Third, combination involves blending of element-specific awareness

patterns into emergent awareness patterns--the qualitative aspect.

Finally, combination involves the merging of element-specific

activity into a global intensity dimension--the quantitative aspect.

Thus, not only does the biofunctional approach specify how

"potential memory" elements (i.e., the microsystems) might be

distributed but it also implies that these elements are distributed

loci of potential subjective qualities.

It appears, therefore, that the concepts of specialization,

constellation, and combination can provide a foundation in terms of

which one can account for the origination of psychological quality

within the biofunctional model. However, a fuller understanding of

this account requires an examination of three specific issues. The

first of these, discussed in the next section, pertains to the

physical locus of subjective qualities. The second, has to do with

the kinds of constraints that exist on possible combinations, and

the third is concerned with singling out the activity of components

of combinations.

Localization and Distribution of Subjective Qualities

As already mentioned, the relationship between brain hardware

and subjective qualities has received a provocative treatment in

Puccetti and Dykes (1978) and the associated commentaries. Puccetti

and Dykes started by pointing out that vision and hearing, for

instance, are qualitatively different subjective experiences. They

then assumed that if subjective qualities are localized in the

brain, one would expect to find corresponding differences in the physical structure of those areas of the brain ordinarily associated with vision and hearing. However, in reviewing the relevant evidence, they could find no support for such structural differences, and concluded that perhaps dualism was the only way out of the dilemma. Sperry (1978), on the other hand, questioned the validity of Puccetti and Dykes' assumption and argued that qualitative differences need not be reflected in "activity in the primary sensory fields of the cortex" (p. 366). Rather, they can emerge from the activity of the brain as a whole. Like Puccetti and Dykes, we assume that differences in psychological quality presuppose differences at the neuronal level, even though we disagree with their corollary assumption that qualitative differences must be evident in the anatomic structure of varicus brain areas. Rather, we assume that different brain areas differ in biofunctional properties and not necessarily in cytostructural characteristics. We also question Sperry's, and Puccetti and Dykes's, claim that the causal loci of subjective qualities cannot exist in particular areas of the brain. In fact, a major goal of the biofunctional theory is to explain differences in subjective quality in terms of microbiofunctional properties of brain areas. According to this view, differences must still exist even if they are not evident in the cytoarchitectural make up of brain tissue.

In terms of the biofunctional model, the solution to the problem of the locus of psychological quality lies in distinguishing between two types of localization. An important implication of

Puccetti and Dykes' argument is that it suggests the need for just
such a distinction. Localization ordinarily refers to the physical
locus of qualitatively complex psychological phenomena (e.g.,
semantic features, concepts, the self), or to the physical locus of
mechanisms that deal with qualitatively complex input (e.g, short-
term memory, pattern analyzers, etc.). Puccetti and Dykes's
approach, on the other hand, suggests that localization occurs
according to qualitatively similar inputs (i.e., visual and
auditory) or qualitatively similar subjective experiences (e.g.,
visual imagery and auditory imagery). It is this type of
localization that is compatible with the notion of distribution
discussed earlier. Neuronal elements are localized in particular
areas of the brain according to their qualitative functional
affinities, elements with similar qualitative properties (e.g.,
those generating spatial qualities) tend to be physically close
together and those with dissimilar qualitative properties (i.e.,
spatial vs. affective elements) tend to be removed from one another.
In other words, the biofunctional theory implies that, in principle,
at the microbiofunctional (i.e., elemental) level, quality is
homogeneously localized. At the macrobiofunctional level, on the
other hand, constellating elements that generate complex and varied
conceptual categories cannot form physically localized groups. It
appears that at this level the complex nature of mental categories
and functions necessarily requires heterogeneous distribution.

A clearer illustration of localization according to
biofunctional affinities of neuronal elements can be found in the

work of O'Keefe and Nadel (1978, 1979) on localization of function

in the hippocampus. These authors have postulated that in order to

find their way around an environment, organisms make use of two

partially independent systems called the locale and the taxon

systems. The locale system, containing (qualitatively homogeneous)

"place-coded" neurons, is responsible for the generation of

absolute, nonegocentric, spatial maps. This cognitive mapping

system, they claimed, is localized in the hippocampus. The taxon

system, on the other hand, is responsible for (qualitatively

heterogeneous) taxonomic or categorical information, comprises the

rest of the brain, and consists of a number of separate subsystems.

O'Keefe and Nadel's approach may be contrasted with that of Olton,

Becker and Handelmann (1979) who have argued that the hippocampus is

the seat of the working memory. These two approaches to

localization are based on very different beliefs about the

functional properties of the brain. O'Keefe and Nadel's approach is

consistent with the biofunctional model in that it implies that

place-neurons, as a qualitatively homogeneous class, form a

localized biofunctional set.

Types of Combinatorial Relations

A system comprising a large number of partially-independent

subsystems must possess combinatorial properties so that

coactivation (or interaction) among the subsystems is possible. For

instance, it can be assumed that only a subset of elements within

each brain subsystem and throughout the entire mass action system,

constellate and reconstellate from moment to moment. Given that

neuronal elements are specialized, and given the assumption that
they can interact at a distance, it is possible to consider
biofunctional relations among distributed elements independently of
the actual neuroanatomic connections.

To characterize the combinatorial relations (i.e. potentials)
of neuronal elements, we adopt a system of relations that was
postulated for somewhat different purposes by Festinger (1957). In
Festinger's system, three types of relations were assumed to exist
among cognitions (cognitive units): consonance, dissonance, and
irrelevance. According to Festinger, cognitions X and Y are
consonant if one follows from the other. When two cognitions have
nothing to do with each other, the relation is irrelevance. And,
finally, two elements are in a dissonant relation, "if considering
these two alone, the obverse of one element would follow from the
other" (p. 13).

Festinger's system of relations can be re-conceptualized as
dynamic combinatorial properties of neuronal elements, rather than
as relations among complex mental units. Recall that an important
consequence of element specialization is that neuronal elements can
generate characteristic energy (or interference) patterns that
provide the necessary and sufficient conditions (i.e., the signals)
for the activation of other elements. This means that the
functional relation between any two elements does not require that
they be connected to one another directly. Rather, in the same
fashion that square-dancers respond to the sound pattern in the air,
which is, loosely speaking, a "complementary combination" of the

sound patterns generated by the voice of the caller and that
generated by the music, the neuronal elements also "dance" to the
"sound" of the dominant interference pattern of the moment that
spreads indiscriminately through the neural network. The difference
is that in the case of the neuronal elements these microsystems are
each simultaneously a caller, a musician, and a dancer--it is a
caller/musician/dancer. Consider, for instance, three elements, A,
B, and C. Suppose that element A is specialized to generate a
unique energy pattern, $E(A)$. Element B is specialized to get
activated in the presence of $E(A)$; and both A and B are specialized
to coact (i.e., engage, for instance, in synchronous rhythmic
activity) in the presence of $E(AB)$, where $E(AB)$ is a consonant (or
complementary) combination of $E(A)$ and $E(B)$. This means that
functionally $E(AB) = E(A) = E(B)$, in much the same way as when
different instruments playing in unison are producing the same tune,
both individually and as a group. To continue the analogy, when B
gets activated it joins the band, and adopts the tune of the
moment. In this sense, there is an A-to-B consonant activity
initiation relationship and an A-B synchronous coactivation
relationship. On the other hand, specialization of elements other
than B would be such that they could not "hear" $E(A)$ or $E(AB)$. This
would mean an A-to-NON-B irrelevant biofunctional relationship.
Similarly, a C-to-B activation-inhibition consonant relationship
might imply a C-to-NON-B irrelevant biofunctional relation.

Now suppose that A and C are active at the same time. $E(A)$
will tend to activate B while $E(C)$ will tend to inhibit it. This

would constitute a _dissonant_ biofunctional relation among A, B, and
C as a constellation. Such dissonance would cause a momentary state
of _dissolution_, by purturbing the prevailing interference pattern
(hence, tending to change its nature from signal to noise),
rendering it ineffective, and thereby breaking the dynamic
combinatorial relations among A, B, C. By analogy, dissonance is
caused by participation of individuals who can hear the music but do
not know how to call/play/dance with it. Dissonance is caused
because these participants continue to engage in activities
incompatible with the ongoing tune and so tend to disrupt the
operation, locally or globally. _Resolution_ can be achieved if a new
interference pattern emerges to support a surviving and/or novel
constellation of elements. This can happen if expert dancers begin
to ignore the unskilled ones, if unskilled dancers drop out, if new
experts join in and act as "tune-translators" for unskilled dancers,
or if the unskilled dancers manage to make their own tune
predominant, in which case those who now cannot tune-in drop out.

Another aspect of the combinatorial potentials of neuronal
elements can be clarified in terms of the analogy to chemical
combination. So far we have assumed that neuronal elements combine
as long as they are consonant. This might seem to suggest that any
number of consonant elements, once active, would combine into a
unified whole. However, it appears more appropriate to
conceptualize consonant elements as forming complementary sets, in
the same way that oxygen and hydrogen form a complementary
combinatorial set, when they combine into water. In other words, we

assume that constellations of elements capable of simultaneous
activity in the context of particular interference patterns form
complementary or <u>coherence sets</u> such that in a particular instance,
if some elements are not yet active the constellation will remain
incomplete. Once all the elements come to be active, the set (and
the macroactive structure) reaches closure. According to this view,
irrelevant elements are defined by their inability to join the
active coherence set of the moment when they get activated.
Dissonant elements, on the other hand, can join in, but unlike
consonant elements, they tend to <u>dissolve</u> or disintegrate the active
pattern by disrupting the prevailing interference pattern. It
should be evident that irrelevance is a biofunctional relation that
is different from consonance or dissonance because it does not by
itself affect the functioning of macroactive patterns. It is
possible, therefore, to consider the quality of activity in the
nervous system as a <u>dichotomous</u> factor (consonance versus
dissonance) as opposed to a trichotomous one (consonance versus
dissonance versus irrelevance).

Simultaneous and Independent Functioning

The notion of consonance provides a way of conceptualizing how
constellations of neuronal elements that are physically distributed
across many brain subsystems can combine via simultaneous (rhythmic)
activity. However, if consonant activity were restricted to
simultaneous activity, the biofunctional system would not work.
Simultaneous activity tends to unify all consonant elements in the
mass action system into a global combination. As mentioned earlier,

in biofunctional combinations, like in chemical combinations,

individual components (i.e., elements or constellations localized

within particular subsystems) tend to lose their qualitative

individualistic properties as they become part of the larger

combination. However, since the activity of the individual

components always occurs in the context of the mass action system

and never in isolation, it follows that these components should be

unable to manifest their individual qualitative properties.

Therefore, a system allowing only simultaneous activity would be

capable of manifesting only global subjective experiences but would

be unable to manifest localized (or finer) qualitative experiences.

It was perhaps for this reason that Bartlett (1932) postulated that

people must have a way of "turning round upon" their schema-of-the-

moment so as to individualize its components.

In order to deal with the problem of component

individualization in the context of the mass action system, we

believe a second type of consonant functioning must be postulated

which we refer to as component independent functioning. Independent

functioning of a component of a larger combination occurs if the

component changes its rate of activity in relation to that of the

combination as a whole. When a component does this, it manifests

its individualistic qualitative properties. In terms of the light

constellation analogy, when a constellation of lightbulbs is on, it

generates a global pattern of light. A bulb, or a subconstellation

of bulbs, can be said to function independently if it becomes

brighter or dimmer than the rest of the bulbs in the constellation.

At the time that the subconstellation is doing this, its characteristic pattern of light (or color) becomes more evident.

It must be noted that any element or any consonant constellation of el ments in t mass action system is, in principle, capable of functioning independently. It must also be noted that in a system of the type proposed here (i.e., one that is exclusively comprised of physically distributed and functionally autonomous elements without containing all-purpose executors or homunculi), independent functioning is the only possible mechanism of component individualization. Thus, the present account, while claiming that the system is homunculus-free, does not specify how individual components come to function independently without a homunculus. However, the biofunctional model does transform the homunculus problem into the more concrete question of how components of the mass action system come to function independently. Clearly, it is conceivable, in terms of the lightbulb analogy, that in a constellation of burning bulbs a subconstellation of them manifests its particular characteristics by growing momentarily brighter or dimmer, that is, by functioning independently of the rest of the larger constellation. More difficult is the question of why this should happen. Presumably, the bulbs do not change their brightness spontaneously--"at will." They cannot manifest spontaneous initiation of activity. But organismic subsystems appear to manifest initiation of spontaneous (or "willful") activity. In other words, organisms are somehow capable of exerting control over organismic subsystems that comprise them (e.g., their limbs). The

biofunctional model implies that this control does not take place

because of the control exerted by some single all-purpose homunculus

embedded somewhere in the system that is somehow capabl of

controlling other qualitatively diverse subsystems. Rather,

spontaneous control is possible because of the influe of multiple

causes all of which, however, exert their influence in terms of

component independent functioning. While this way of viewing

apparently spontaneous initiation of organismic activity concretizes

the problem, our intuitions as to the cause of spontaneous

independent functioning of components add little to those of

Bartlett. Bartlett (1932) believed that the problem of component

individualization was unanswerable at the time but he insisted that

it had to somehow occur. He also maintained that whatever form a

satisfactory answer to the problem turned out to take, subjective

determination (i.e, awareness mediation) would have to be involved

(see Iran-Nejad, 1980; Iran-Nejad & Ortony, 1982). One way in which

awareness-mediated component independent functioning might work can

be illustrated by considering the tip-of-the-tongue phenomenon.

Perhaps this phenomenon occurs when a person is implicitly aware of

a particular component of the mass action system but is not

sufficiently so to make it function independently and, thereby,

explicit. There are also more automatic instances of component

independent functioning. For example, independent functioning can

occur in direct response to external energy patterns, as when one

looks at a flashing light or when one encounters surprising

information.

In addition to individualization, component independent

functioning serves two other basic functions. First, it is an

awareness-enhancing mechanism. This is, of course, a restatement of

an earlier claim that when a component functions independently, it

manifests its characteristic qualitative properties. Secondly,

independent functioning is an attention mechanism; that is, an

independently functioning component becomes the center of focal

attention for the duration that it is functioning independently.

Thus, according to the functional theory, component

individualization, awareness, and attention are mediated by a single

mechanism--component independent functioning.

It is possible that the two types of consonant functioning

postulated here--independent and simultaneous--are responsible for

the two types of brain wave activity often observed in EEG records.

One type of brain wave, the synchronized slow electrical activity,

is more evident when the cortex is relatively idle. Since these

slow electrical rhythms also occur during slow-wave sleep, many

investigators have concluded that synchronizing activity is totally

passive, that slow electrical activity is only epiphenomenal to the

activity of the brain, and that no active synchronization is

involved in psychological functioning. On the other hand,

psychological activity has been assumed to occur when slow-waves are

less evident and when desynchronized activation becomes prominent

(see, e.g., Jasper, 1981). In terms of the biofunctional theory, it

may be argued that slow-wave synchronizing activation occurs as a

result of simultaneous functioning, and that desynchronized

electrical activity occurs as a consequence of component independent
functioning.

The Schema-of-the-Moment: nc al   istic and   ctions

We have .ow   ti   a   in   u: prop   neuronal
microsystems, how they are physically distributed, how they
intercommunicate, how they generate psychological qualities, and how
they engage in simultaneous or independent functioning. We have
characterized the neuronal system as a dynamic mass action system
consisting of a large population of specialized neuronal elements
which can combine in activity to form functional constellations. We
have proposed that specialized neuronal microsystems, as elementary
loci of subjective qualities, constitute the basis not only for
distributed (potential) memory, but also for distributed awareness
and distributed attention. Simultaneous functioning was proposed as
the mechanism for both implicit and global awareness, as well as for
broad attention. Component independent functioning, on the other
hand, was postulated as a mechanism for focal awareness and focal
attention.

With these concepts, it is now possible to present a rather
explicit account of the schema-of-the-moment, which is, loosely
speaking, the subjective counterpart of the activity in the mass
action system. In this section we shall discuss the main
characteristics of the schema-of-the-moment. In particular, we will
discuss the stability of different components of the schema-of-the-
moment and its overall continuity; we will argue that the organizing
forces of the schema-of-the-moment are content-based rather than

structure-based, and we will try to specify the nature of changes that occur in the schema-of-the-moment in response to incoming information. Since we believe that our concept of the schema-of-the-moment is similar to that suggested by Bartlett (1932), much of our discussion will involve elaborations or clarifications of his ideas.

Stability and Continuity

The schema-of-the-moment is a constantly changing phenomenon involving both global and focal experiences. With respect to stability and change, the totality of the schema-of-the-moment may be viewed as comprising three theoretically distinguishable, but not actually separate, components. We will refer to these as the background component of the schema-of-the-moment (Background-SOM), the dominant component of the schema-of-the-moment (Dominant-SOM), and the independently functioning component of the schema-of-the-moment (Independently-Functioning-SOM). The Background-SOM is a slowly-functioning loosely-integrated component in which elements with consonant, dissonant, and irrelevant functional properties can coexist. It involves the major portion of the schema-of-the-moment and the majority of the elements in the mass action system. Because of the slow rate of activity in the Background-SOM, it remains the closest component to the microbiofunctional level. This is because at low levels of activity, there is less functional integration and, consequently, the active elements will tend to preserve their localized individualistic functional properties. This component is responsible for the background or peripheral awareness of such

things as time, space, self, and various other "active" content

domains. The background-SOM is ordinarily a stable component of the

schema-of-the-moment and most of its elements maintain an activity

rhythm that can last for hours, weeks, months, or even years without

undergoing significant change. Major shifts in this component,

however, do occur especially during landmark occasions such as

unusual personal successes or failures, personal tragedies, and, to

some extent, during less dramatic changes in normal life patterns

such as travel and vacations. More subtle changes in the

Background-SOM occur as a function of interaction with other

components of the schema-of-the-moment. The Background-SOM remains

stable to the extent that its elements fail to participate, because

of their irrelevance, in other components of the schema-of-the-

moment.

The second major component, the Dominant-SOM, results from

simultaneous macroactivity in consonant elements of the moment.

This component depends for stability on its incompleteness and,

occasionally, on rehearsal. More specifically, an incomplete schema

tends to remain dominant longer than a complete one, because an

incomplete schema remains active through development while a

complete schema can remain dominant merely through effortful

rehearsal. A person is only globally aware of activity in the

Dominant-SOM and has only implicit awareness of its components.

With respect to the nature of ongoing activity, the Dominant-SOM may

be either resolving or dissolving. A resolving Dominant-SOM

consists of an incomplete set of consonant elements and tends to

remain active until closure is reached through element enrichment

(i.e., through activation of other consonant members of the

coherence set), after which time it can only remain dominant through

rehearsal. A dissolving Dominant-SOM consists of consonant and

dissonant elements and tends toward resolution through

disintegration. A dissolving Dominant-SOM may end up in total

disintegration through what might be called element shedding (i.e.,

the loss of active consonant elements). Element shedding may also

result in partial disintegration when "dissonance-infected"

consonant elements drop out until no such elements are involved, at

which time the remaining consonant elements may initiate a resolving

Dominant-SOM. Experientially, resolving Dominant-SOM activity

manifests itself as feelings of consistency, curiosity, suspense,

understanding, interestingness, and closure. Dissolving Dominant-

SOM activity, on the other hand, gives rise to experiences of

conflict, fear, anxiety, confusion, aversion, and lack of closure.

The third major component is the independently functioning

schema-of-the-moment, Independently-Functioning-SOM. This is the

most transitory component of the schema-of-the moment, since it soon

joins either the Dominant-SOM, if it is consonant or dissonant with

it, or the Background-SOM, if it is irrelevant to the Dominant-SOM.

This tripartite characterization of the schema-of-the-moment is

not meant to suggest that the three components are actually

distinct. First, the initial creation of the Dominant-SOM occurs

when some elements in the Background-SOM come to function

independently, under the influence of external stimulation, for

instance. Subsequently, the Background-SOM serves as the context

for the development of the Dominant-SOM and as the only source of

element enrichment for it. Subsequent Dominant-SOM enrichment is

mediated by the activity of the Independently-Functioning-SOM. It

occurs when elements in the Background-SOM consonant with those in

the Dominant-SOM come to function independently, either as a result

of changes in the external stimulation, or as a result of changes in

the internal relational environment which is, in turn, caused by the

activity in Dominant-SOM. In this way, the three components of the

schema-of-the-moment continue to interact and to create the

constantly changing phenomenal experience of the moment. So, if the

biofunctional model is correct, there are no individual mental

entities—there are no cognitive building blocks. There is total

continuity, not only with the immediate external or internal

context, but also in time, in space, and with respect to personal

history. In spite of this total continuity, it is often possible to

single out particular components of the schema-of-the-moment. But,

even when focussing on a single "distant" component, the continuity

is never lost. A quick excursion to a remote childhood experience

does not destroy the experience of the moment. It seems that it is

always the past that "visits" the present (by getting re-created

when the conditions are suitable) and not the present that searches

for the past. Transitions are almost always smooth and continuous.

The Primacy of Content over Structure

Even though we claim that there exist no long-term static

structures in the head, we still have to explain the origin of

transient structures. Our explanation here is essentially the same
as Bartlett's (1932), although Bartlett did not make his theory very
explicit. In the model we are proposing, neuronal microsystems are
the biofunctional generators of primitive psychological qualities.
At a slightly less biological level, Bartlett (1932) referred to
these primitive qualities as "images" (including what he called
percepts, appetites, instincts, ideals), and claimed that images are
the basic ingredients of the schema-of-the-moment. According to
functional models of this sort, the only type of structure that can
exist is the structure of organized content--structure cannot exist
independently of content (Shanklin, 1981). Thus, if our
interpretation of Bartlett is correct, his functional schema theory
is very different from the kinds of structural schema theories that
it has spawned. Structural theories are based on the assumption
that relatively content-free abstract structures serve to organize
content. Bartlett's theory, on the other hand, seems to suggest
that content possesses intrinsic organizing properties that
constantly produce and reproduce structure thus eliminating the need
to postulate abstract organizing structures. Furthermore, while in
his theory, Bartlett stressed that schema bias, or "determination by
schemata" as he called it, is a critical factor in cognitive
functioning, he also insisted that there is an even more potent
bias, namely, the bias inherent in the qualitative properties of
specific content elements. Element bias is more potent because, for
instance, it makes it possible to skip directly to events that
occurred in the remote past despite the determinism of the current
schema-of-the-moment:

In the experiments on perceiving, or imaging, and on all the
various modes of recall, while there was a sense in which
subjects could accurately be said to have reacted to whatever
material was presented 'as a whole,' yet in that whole some
special features were invariably dominant. In many cases, when
the material had to be dealt with at a distance, as in
remembering, the dominant features were the first to appear,
either in image form, or descriptively through the use of
language. In fact, this is one of the great functions of
images in mental life: to pick items out of 'schemata,' and to
rid the organism of over-determination by the last preceding
member of a given series. (p. 209)

Bartlett illustrated how the reappearance of some key content
elements enabled one of his subjects to remember a story after more
than ten years. Bartlett maintained that remembering begins with a
global impression built around a few dominant details from the
original experience, an impression which is primarily of the nature
of affective quality. After the establishment of this global
impression comes the immediate return of other details that may
contain "some inventions and transformations, [but] seem clearly to
be derived from some of the events of the original story" (p. 209).
Bartlett maintained that in any learning or remembering situation,
the "dominant, or over-weighted, elements [that] stand out from the
rest ... together with their determining tendencies, are apt to set
the meaning of that situation" (p. 234). Thus, according to
Bartlett, the qualitative properties of a few content elements cause

a global impression that sets the stage for the recall of past
experiences.

Similarly, the biofunctional model assumes that at the most
primitive level content elements are created by neuronal elements.
When a subconstellation of neuronal elements representative of those
that were active at the time of the original experience get
activated (e.g., as a function of the stimuli provided by seeing and
talking to an experimenter and by the recall probes provided), it
generates element-specific awareness patterns that combine to create
the global impression. The elements also generate element-specific
energy patterns that combine to create the relational environment
that existed at the time the material was originally learned. The
relational environment then sets the stage for the activation of
other consonant elements that enrich the global impression. The
result is a schema-of-the-moment that approximates an earlier
experience.

The square-dancing analogy used earlier can illustrate how this
might happen. Recall that individual neuronal elements were likened
to individual square-dancers with the difference that neuronal
elements not only served as dancers but, at the same time, as
caller/musicians. One can imagine how a few caller/musician/dancers
might initiate a performance in a large crowd. Soon the sound of
their music pervades the air and more and more individuals join in.
Similarly, once they come to be active, a few neuronal element's that
participated in an earlier experience can re-create a relational
environment (a tune) uniquely representative of that experience.

Acquiring New Information: Combination or Slot Filling

One of the most widely studied aspects of conventional schema
theories is the slot filling thesis. According to this, a schema is
an abstract frame that contains slots which are filled by incoming
schema-related information. A corollary of the slot filling thesis
is that people only learn what they have schemata for and ignore
everything else (Neisser, 1976). The thesis has trouble with the
fact that people can and do remember incongruous information (see,
Schallert, 1982; Thorndyke & Yekovich, 1980).

It must be acknowledged that there have been attempts to deal
with the processing and recall of incongruous information within
conventional schema theories (see e.g., Schank & Abelson, 1977 and
Schank, 1982 on expectation failures). One approach, studied
extensively by Graesser and his associates (Graesser, 1981;
Graesser, Gordon & Sawyer, 1979; Graesser, Woll, Kowalski & Smith,
1980; Smith & Graesser, 1981; Woll & Graesser, 1982) defines
schema-relatedness in terms of typicality--the more typical an item
of information the more likely it is to be in the schema. To the
extent that an item is schema-atypical, it is to be considered
unrelated or incongruous. In this approach, an atypical item is
recalled because at the time of learning it is indexed as such, that
is, it "is encoded with a distinctive, unique tag and stored as a
separate unit" (Woll & Graesser, 1982, p. 290).

Even if salvaged through some kind of indexing scheme, the slot
filling thesis suffers, we think, from another problem related to
the fact that it implies that new information or content fills the

slots provided by the schema _passively_. However, if the

biofunctional model is correct in claiming that content elements

possess their own functional properties, then these elements must

play an active combinatorial role. In fact, the claim that content

elements exert their own "active biases" was one of the recurrent

themes in Bartlett's theory. He argued that the "active biases"

caused by new incoming information play a dominant role in the

comprehension of both congruous and incongruous information.

Furthermore, Bartlett cautioned against a passive slot filling

interpretation of his theory:

> The process is not merely a question of relating the newly
>
> presented material to old acquirements of knowledge.
>
> Primarily, it depends upon the active bias, or special reaction
>
> tendencies, that are awakened in the observer by the new
>
> material, and it is these tendencies which then set the new
>
> into relation to the old. To speak as if what is accepted and
>
> given a place in mental life is always simply a question of
>
> what fits into already formed apperception systems is to miss
>
> the obvious point that the process of fitting is an active
>
> process. (p. 85)

For Bartlett, therefore, incoming information does not

passively fill slots that are made available by the operative

schema. Rather, it is the potential of the new information to

a qualitative "active biases" that sets "the new into relation

to the old." In other words, what is newly acquired actively

combines with what is old. The word _active_ must be interpreted with

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caution here. It means that what is "awakened" by the new information does not surrender itself passively to the shackles of an _active_ schema. Rather, the new information imposes "active biases" of its own that often override the biases imposed by the schema-of-the-moment, as when incongruous information spontaneously draws attention away from the operative schema. Furthermore, if our interpretation of Bartlett is correct, in his theory, and certainly in the biofunctional model presented here, the potential for content elements to play an active role exists _after_ learning as much as it does at the time of learning. In other words, being functionally autonomous, these elements do not remain chained passively to a structure after they combine with it until that structure is reactivated, any more than dancers freeze into a "solid" frame as soon as the tune to which they are dancing stops. Being autonomous individuals, each dancer can participate in a different activity in the meantime. Dynamic combination is not a long-term bond. It is some sort of momentary cooperative activity (see Freeman, 1975), a cooperation to create something novel.

Bartlett's observations about the nature of learning and remembering are completely compatible with those implied by the biofunctional model. The biofunctional model explicitly rules out the preservation of static relations and of abstract structures. The only option open, therefore, is to explain remembering in terms of the functional properties of autonomous neuronal elements and not in terms of st ic ntal relations. In he biofunctional model, the only _relations_ that can be preserved are transient functional

relations--active, concrete, and particular functional relations--
where active, concrete, and particular mean on-going biological
activity in a particular organismic system. As Bartlett put it
"what is essential to the whole notion" of a schema is that it is
"actively _doing_ something all the time ... [it is] carried along
with us, complete, though developing, from moment to moment" (1932,
p. 201).

The term _transient_ also needs some qualification. There is a
sense in which transient functional relations could last a long
time, that is, if the activity involved continues in 'the manner
postulated by Bartlett and specified in this paper. A square
dancing session is inherently transient, but it could, in principle,
last for days, weeks, or even years. Therefore, if our
interpretation of Bartlett is correct, his theory was not based on
the preservation of abstract long-term relations underlying generic
information, as has been suggested by some authors (see e.g., Woll &
Graesser, 1982). On the contrary, he held that every piece of
generic or abstract information, or any other complex mental
structure, had to be re-created afresh based on the qualitative
properties of active elements. What is permanent is the elements
themselves (for Bartlett "image-like" content elements and in our
model neuronal microsystems). This is probably why Bartlett
emphasized the tendency of subjects to preserve the concrete. For
instance, he stated that:

> [In folk-tales and] in other types of material, every general
> opinion,   ry piece of reasoning, and every

deduction, is speedily transformed and then omitted. The

greatest efforts in this direction were achieved by subjects

who reported a visual method of recall, as if this method

carries with it an inevitable bias towards the concrete. .The

tendency observable in several instances for a narrative, a

description, or an argument to take on a personal form, seems

to be due in part to the same factor. . . . It may, at first,

seem that the mass of folk-proverbs which are traditionally

preserved among every people contradicts the tendency toward

the concrete. But the strength of the folk-proverbs lies in

its applicability to the individual instances. As a mere

generality it never would have been preserved and, except in a

literary sense, it is practically never used. (pp. 172-173)

Bartlett maintained that acquisition of new information

involves two basic functions. First, there is an immediate

physiological function made possible by the reaction of a sensory

mechanism to external stimuli. This, he believed, is already

selective; its selectivity is determined by the qualitative

properties of the stimuli involved, and it approximates what is

generally meant by hearing, seeing, and so on. The second function

has to do with the reaction of the organism as a whole to the

immediate physiological pattern of activity. This is also selective

but its selectivity is made possible, not by some localized

mechanism, but by the global qualitative properties of the active

mass of the moment. This, Bartlett maintained, approximates what is

generally called listening as opposed to hearing, or looking as

opposed to seeing. Bartlett believed that the type of selectivity
that is directly based on "qualitative factors is dominant over any
other type in all the higher mental processes" (p., 190). This
selectivity makes it possible to gather, from among elements present
both in the active sensory pattern or in the active mass of the
moment, those elements that are "most relevant to the needs of the
moment" and so to construct an updated schema. He maintained that
construction is either spontaneous and immediate, or that it is
mediated by what he called effort after meaning, effort to relate
"what is given to something else" or to understand what is not
immediately obvious.

Bartlett's theory can be readily specified in biofunctional
terms. According to the biofunctional model, sensory stimulation
causes independent functioning of a constellation of neuronal
elements and creates a momentary Independently-Functioning-SOM which
then interacts with the Dominant-SOM in the following fashion: If
the Independently-Functioning-SOM, or a subconstellation of its
elements, is consonant with (but not necessarily typical of) the
Dominant-SOM, it will combine with it. Those elements in the
Independently-Functioning-SOM that are irrelevant to the Dominant-
SOM become part of the Background-SOM, even if they happen to be
typical of the situation in which the Dominant-SOM is active (e.g.,
the waitress serving in a restaurent has brown hair). If the
Independently-Functioning-SOM, or a subconstellation of its
elements, is dissonant with (but not necessarily atypical of) the
Dominant-SOM (e.g., long waiting lines are annoying in restaurants),

it will cause a temporary state of dissolution in the Dominant-SOM

by causing a purturbation in the internal relational environment and

by changing the nature of the energy pattern of the moment from

signal to noise. Dissonance is resolved if the Dominant-SOM

undergoes spontaneous element enrichment or element shedding. The

diners may be relieved to see an acquaintance in the line who is fun

to talk to while waiting, or they may give up waiting and go to an

otherwise less preferred restaurant. If resolution cannot occur,

the dissonant Independently-Functioning-SOM becomes part of the

Background-SOM. The diners might decide to wait, move their

thoughts to a different topic, but, at the fringe of their

awareness, they might still remain troubled hy the long wait.

Resolution or lack of it is caused by localized element bias effects

and hy global schema bias effects, both of which are caused by the

functional properties of elements and both of which together

manifest themselves in terms of effort after meaning.

According to the biofunctional model, therefore, to the extent

that the Independently-Functioning-SOM combines with the Dominant-

SOM, it will lose its distinctive qualitative characteristics, just

as oxygen and hydrogen lose their combustible properties when they

combine to form water. This is how the combination hypothesis

explains the fact that in recognition memory new items can be

difficult to discriminate from similar old items. More

specifically, it is impossible to discriminate already integrated

old information from new information that differs from it only by
distinctive properties that are lost as a result of the act of
combination.

Sources of Functional Initiation

The assumption that long-term static structures do not exist,
and the complementary claim that mental relations are established
only after neuronal elements are already active, raises the problem
of how neuronal elements come to be in a state of functioning to
begin with. This problem seems particularly urgent in relation to
remembering. If mental structures are transient, how can people
remember anything? How can they recall together what they have
learned together if they have not stored it together? That these
questions appear to be so challenging seems to us to be a reflection
of the deep-seatedness of the permanent-storage metaphor, which also
seems to be responsible for widespread rejections or
misinterpretations of Bartlett's reconstructive theory of
remembering (see Iran-Nejad, 1980).

Bartlett (1932) rejected the long-term storage metaphor and
proposed that remembering is reconstructive or re-creative. In
support of his claim, he showed that recall is often inaccurate.
Some researchers (e.g., Zangwill, 1972) have treated reconstruction
as if it were equivalent to inaccuracy in recall and have considered
the fact that recall is often accurate as evidence against
Bartlett's theory. Although Spiro (1977) argued against this
interpretation of the notion of reconstruction, authors continue to
fail to distinguish between reconstruction and the mere occurrence

of recall errors. For instance, a recent review of research on

schema theory concluded that "the consensus is that reconstruction

[i.e. as evidenced by the incidence of recall errors] is quite rare

and occurs only under special circumstances" (Alba & Hasher, 1983).

Several other researchers, on the other hand, have followed

Bartlett, as we have, in calling into question the long-term storage

metaphor and in maintaining that remembering is re-creative (see,

e.g., Bransford et al., 1977; Jenkins, 1977). However, the issue of

how accurate recall is possible given only transient functional

relations has yet to be resolved.

According to the biofunctional model, in order to demonstrate

how recall is possible without long-term storage of static

structures, the problem of remembering must be considered in terms

of two separate problems, namely, the problem of specifying the

sources of functional initiation in neuronal elements, and the

problem of specifying what happens following such functional

initiation.

The causes of initiation of (or changes in) activity in

elements can only be understood by recognizing that the nervous

system is a multiple-source dependent system with respect to

functional initiation. First, there are endogenous sources of

functional initiation that arise within the organism. Endogenous

sources may be biological, biofunctional, or mental. That hungry

individuals are more likely to seek food has perhaps more to do with

biological sources of initiation than with other endogenous sources.

While we cannot specify the relative contribution of biological

factors and their interaction with biofunctional, psychological, or
environmental sources, the fact that such factors exist is well-
established (see, e.g., Colquhoun, 1971). The major biofunctional
source of initiation of functioning, according to the present model,
might be called the combinatorial source. As elements combine, they
create novel energy (or signal) patterns that set the stage for the
initiation of functioning in other elements through the
establishment of emergent functional relations. There are also more
subtle biofunctional sources that play a critical role. A large
number of neuronal elements in the Background-SOM are specialized to
maintain a particular biofunctional rhythm or cycle. Endogenous
sources responsible for awakening organisms from sleep might be
largely of this type. The main psychological source of functional
initiation in neuronal elements is assumed to be the Dominant-SOM.
How the Dominant-SOM acts as a source of initiation of functioning,
or whether it is the only component of the schema-of-the-moment
through which the mind influences the activity of the brain, is a
question that we cannot yet answer.

The final but perhaps the most important source of functional
initiation as far as the stability and the development of '.e
schema-of-the-moment are concerned, are exogenous sources--those
external energy patterns (or signals) that constantly influence the
neuronal system through several independent sense organs. It seems
as though nature has found it profitable to relate organisms to the
world through more than one sense organ, each serving as an
independent source of functional initiation.

The multiplicity of sources of functional initiation means that

after initiation of activity, the development of the schema-of-the-

moment is not a straightforward combination of functioning elements.

Rather, "the complexity of 'schematic' formation means that many

objects, many stimuli, many reactions, get organized simultaneously

into different cross-streams of organized influences" (Bartlett,

1932, p. 302). Thus, the qualitative characteristics of autonomous

elements play a vital role in the re-creation of past experiences

and in the creation of new ones. Consequently, after functional

initiation, there is a more critical phase in the development of the

schema-of-the-moment that must be taken into account. According to

the biofunctional model, the nature of activity in this phase is

solely determined by the qualitative functional properties of

neuronal elements, both at a global level (as manifested in schema

bias) and at a local level (manifested in terms of element biases).

Earlier, we used the term enrichment to refer to the development

toward closure of the Dominant-SOM. However, since multiple-source

functioning means activation of dissonant elements, activity in the

Dominant-SOM during the enrichment phase, might also be viewed as an

act of problem-solving. According to this view, post-initiation

enrichment is guided by two basic types of subjective qualities,

which are determined by dissonant and consonant biofunctional

properties of active neuronal elements and which tend to manifest

themselves in terms of what might be called problem recognition and

resolution recognition capacities. If the biofunctional theory is

correct, problem-solving during recall, and problem-solving in

general, must operate toward justification of these two types of

subjective qualities. It is this problem-solving nature of remembering that renders recall inaccurate or accurate, as far as "the actual facts of the learning situation," as Bartlett put it, are concerned, since post-initiation problem-solving makes remembering totally dependent on the Dominant-SOM at the time of recall. Accuracy in recall is determined by the degree to which the actual facts of the recall situation, especially those that serve as the sources of functional initiation, approximate those of the learning situation.

Conclusion

We have attempted to sketch a model of the mind that we hope is compatible with what is known about the brain and the nervous system. Our primary goal has been to address questions relevant to psychology as opposed to artificial intelligence. We have tried to show how cognition is possible in an animate system having the kind of biological constraints that humans have, rather than how cognition might be possible in some more abstract "system-independent" manner. This choice was made because we believe that the nature of human cognition and experience is necessarily determined by the way in which the individual components of the system function.

A second goal was to bridge the gap between cognitive psychology and the neurosciences. To the extent that we have succeeded, the result is a model that strictly speaking does not conform to the standards of either neuroscientific models or of psychological ones. We have drawn upon what we judged to be

relevant literature in both the neurosciences and cognitive

psychology. Given the diversity of this literature, and given our

own particular goals, it is likely that some of the authors of the

ideas we have used will find our approach difficult to accept. In

employing the proposals of others, we have taken care to specify

clearly those aspects of their work we have found attractive. Thus,

for example, our endorsement of Sperry's proposals about

consciousness in no way entails a commitment to his general

philosophy.

There are doubtless many problems with the model we have

proposed, and perhaps with the way we have presented it. We hope

that these problems are no more serious that those facing

conventional models. On the positive side, we think that a model of

the type we have presented might be able to provide a solution to

some of the more complex philosophical problems having to do with

mental representations discussed, for example, by Dennett (1983).

Like Dennett, the central claim we have made is that it is neither

necessary nor is it ultimately fruitful to conceive of knowledge

representations as stored abstractions upon which various kinds of

cognitive processes operate.

In a paper of this kind, it is not possible to do all that one

would like. We have resisted trying to propose detailed accounts of

the huge range of aspects of mental life--each would take a book.

We have also not discussed the empirical consequences of the view we

have proposed because that would have necessitated just such

detailed discussions of the individual aspects of cognition. We

have preferred to present an impressionistic sketch of our account

from which, hopefully, the big picture emerges even if some of the

details are absent or do not accurately portray the way things

really are.

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[1]There is a striking parallel between the approach taken by the
Roman physiologist Galen (c.AD 130-201) and current information
processing psychology--information processing psychology is based on
the same type of industrial plant metaphor that haunted Galenian
physiology (see Miller, 1978). Galen was concerned with how
inanimate matter, as the input to the body via foodstuff, is
transformed to animate matter. Internal organs (e.g., the heart,
the liver, the lungs) were considered relevant to the extent that
they helped carry out such transformations. In Galen's physiology,
as in information processing psychology, "the most notable feature
of the system is the emphasis on manufacture and transformation
. . . processes which convert . . . substances" (Miller, 1978,
p. 187).